UNIVERSITEIT GENT

FACULTY OF ENGINEERING AND ARCHITECTURE

NUMERICAL AND EXPERIMENTAL STUDY OF SECONDARY FLOW FEATURES IN A GAS VORTEX UNIT

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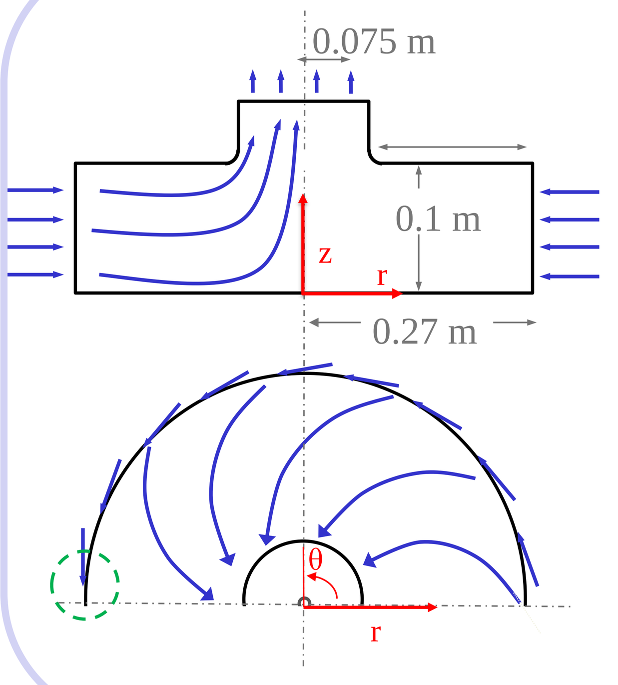
ERIC European Research Institute of Catalysis

M2dRC Methusalem programma

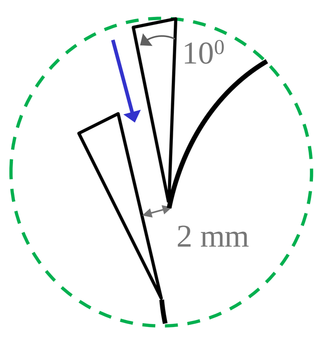
Introduction

- Centrifugal field generated by azimuthal injection of gas into a confined disc-shaped static chamber.
- Gas only flow: potential applications such as flame stabilization, clean combustion from secondary flow features.
- Gas-solid flow: dense rotating fluidized bed with high slip velocities suitable for fast reactions such as biomass pyrolysis.

The Gas Vortex Unit

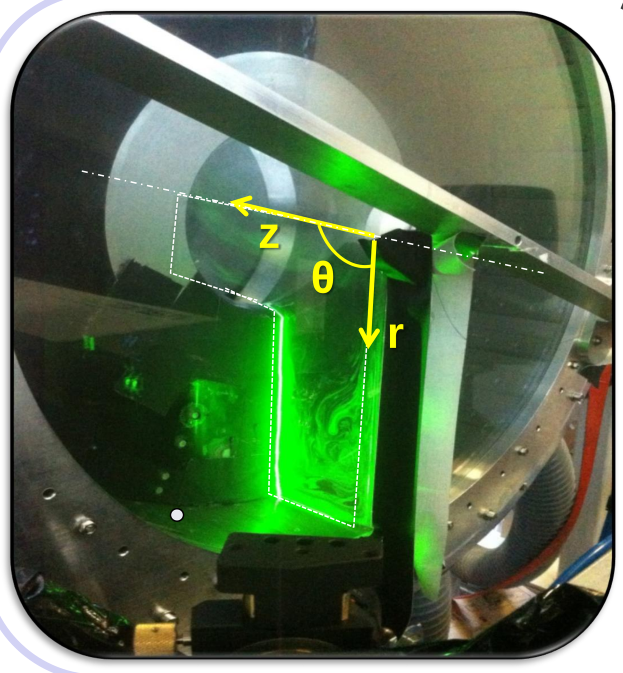


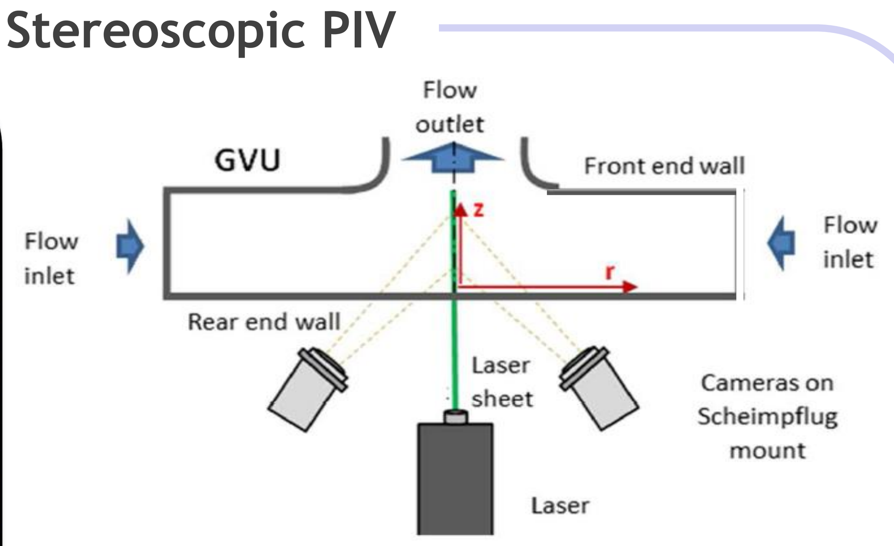
Swirl ratio= 12
$Re_{sup,inj}$ =13,000
A_{in}/A_{tot}= 0.042
G_M = 0.4-0.8 Nm^3/s
V_{inj}=45-120 m/s



Experimental Techniques

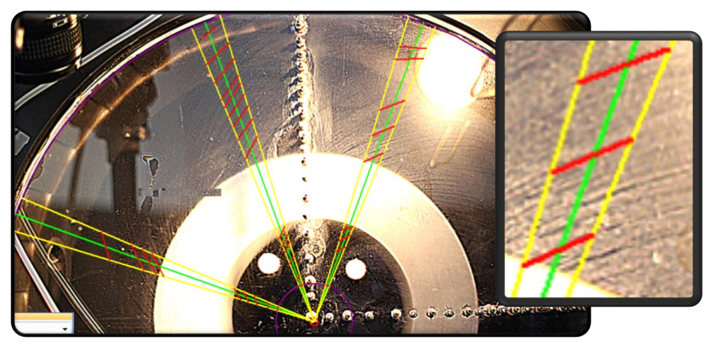
Stereoscopic PIV





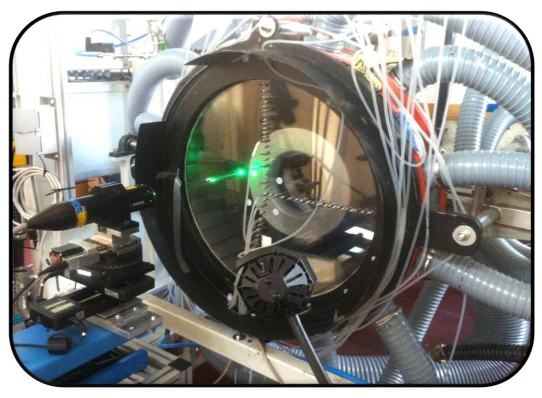
3-D Velocity in a Plane

Oil film visualization & DIA



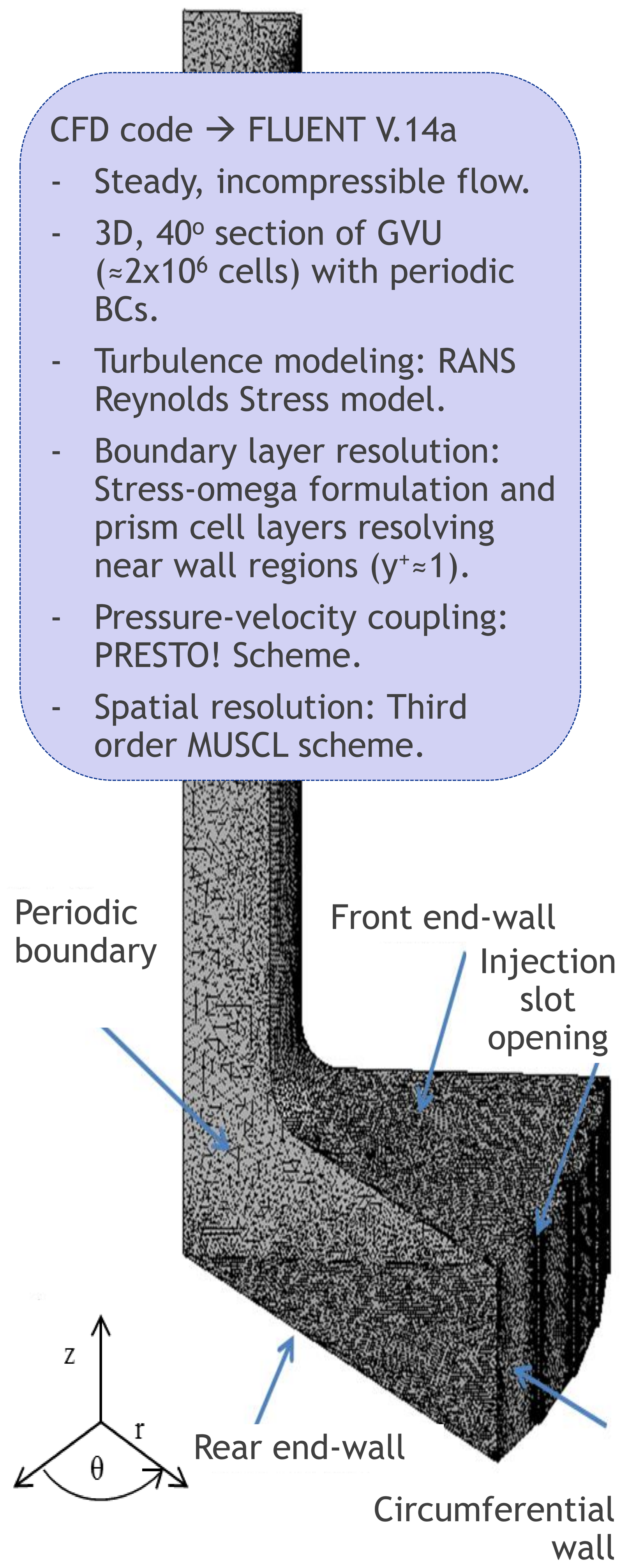
Surface streamlines

LDA



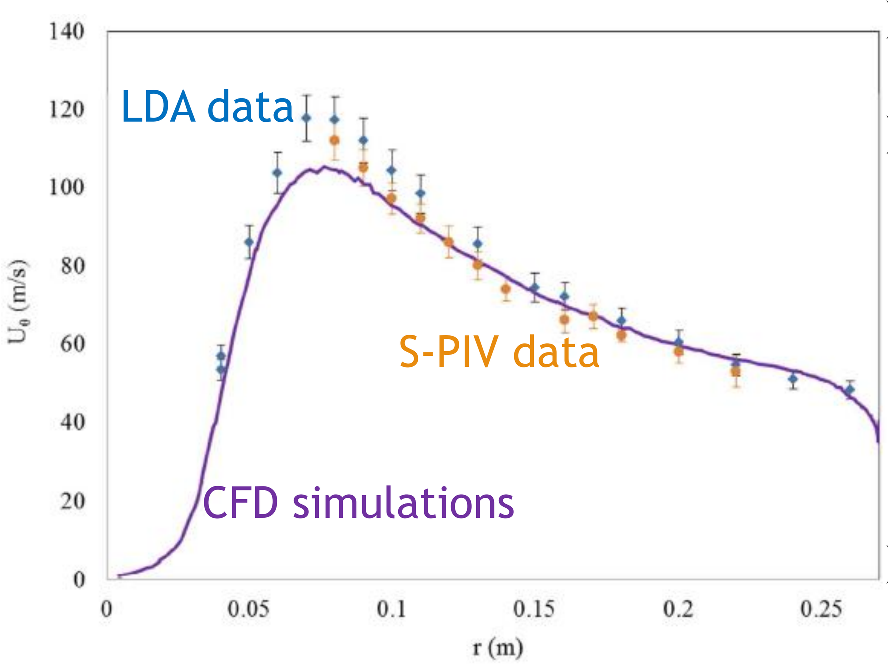
1D velocity in a point

CFD Simulations



CFD code → FLUENT V.14a
- Steady, incompressible flow.
- 3D, 40º section of GVU (≈2x10⁶ cells) with periodic BCs.
- Turbulence modeling: RANS Reynolds Stress model.
- Boundary layer resolution: Stress-omega formulation and prism cell layers resolving near wall regions ($y^+ \approx 1$).
- Pressure-velocity coupling: PRESTO! Scheme.
- Spatial resolution: Third order MUSCL scheme.

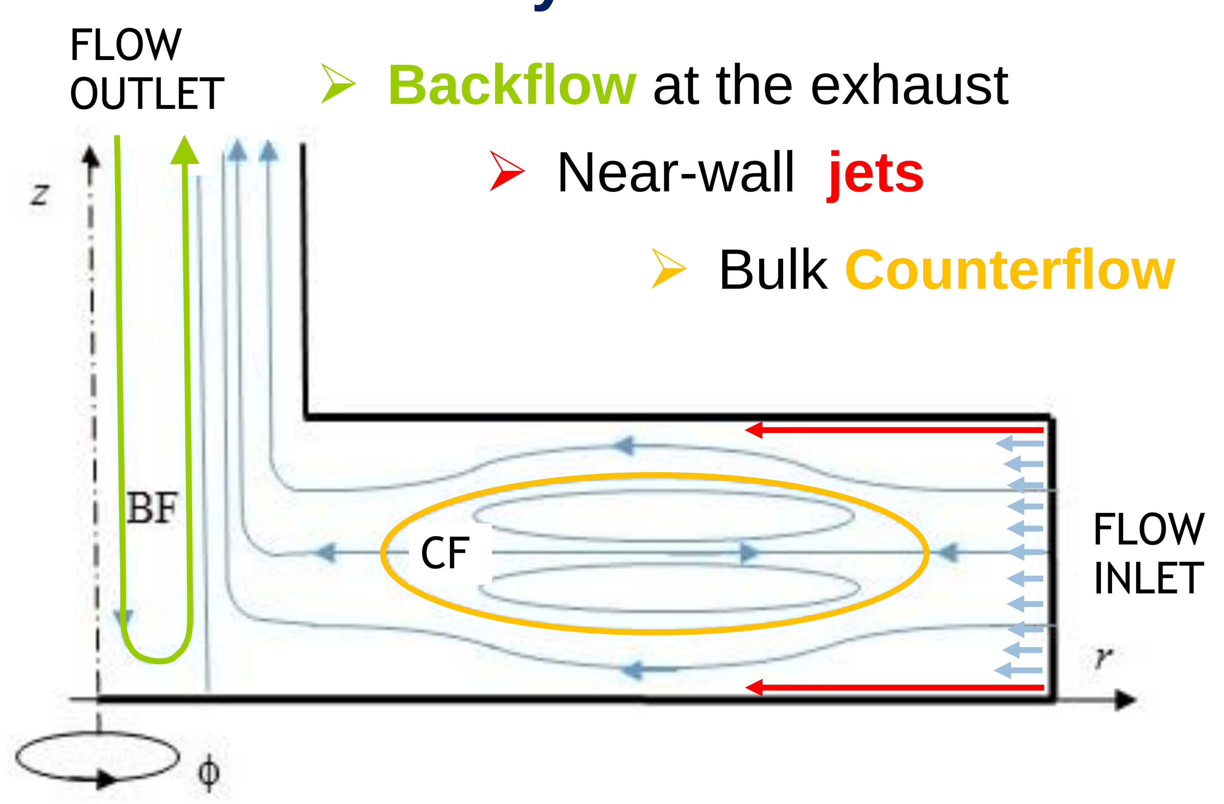
Bulk Flow



Azimuthal velocity profiles at θ=20°, z=0.05 m. G=0.4 Nm^3/s. 95 % CI

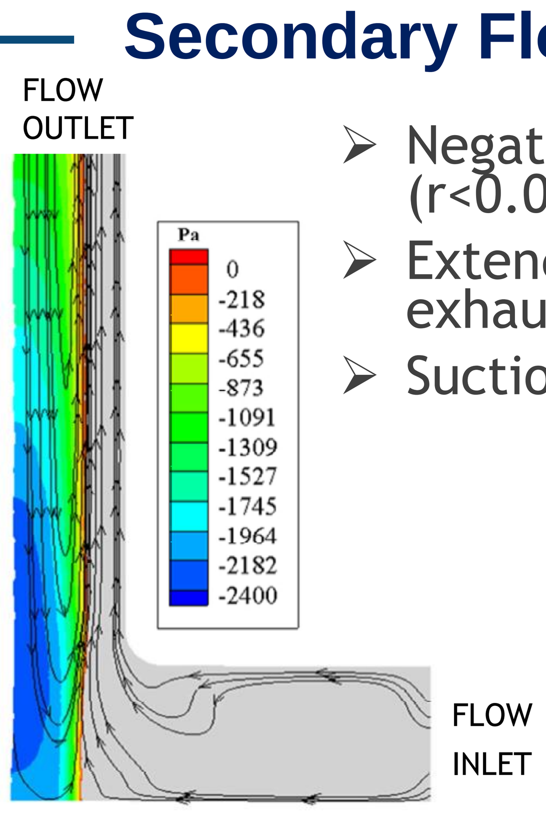
- High swirling flow
- Combination of
  - ✓ Free vortex flow
    $r\,U_\theta = constant$
  - ✓ Solid body rotation
- Swirl induces turbulence due to secondary flow formation

Secondary Flow Features

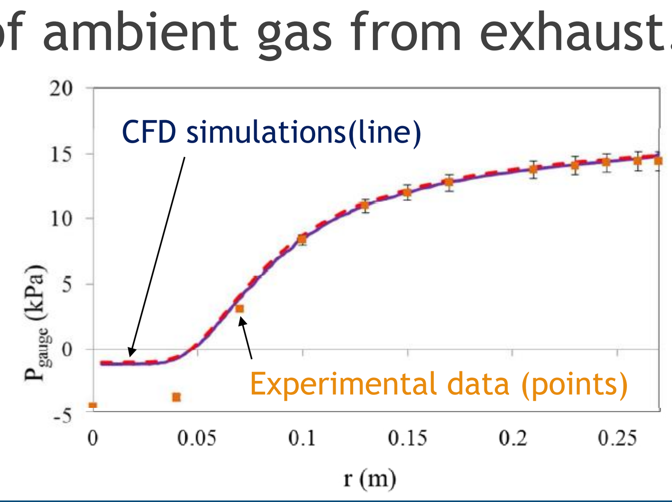


- **Backflow** at the exhaust
- Near-wall **jets**
- Bulk **Counterflow**

Secondary Flow Feature: Backflow



- Negative gauge pressure near axis (r<0.05m).
- Extended backflow region along the exhaust.
- Suction of ambient gas from exhaust.



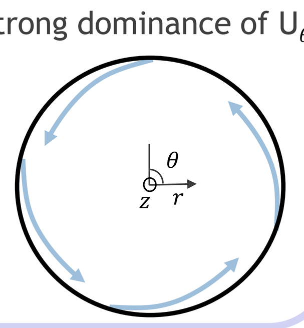
Secondary Flow Feature: Jets

Bulk flow (0.005 m < z < 0.095 m)

Momentum balance reduces to cyclostrophic balance

$$\frac{\partial P}{\partial r} = \frac{\rho U_\theta^2}{r}$$

Strong dominance of U_θ

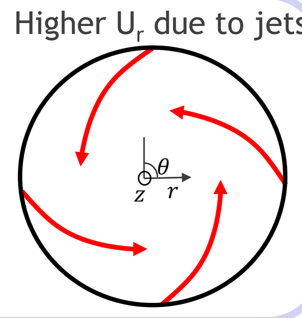


Near-walls flow

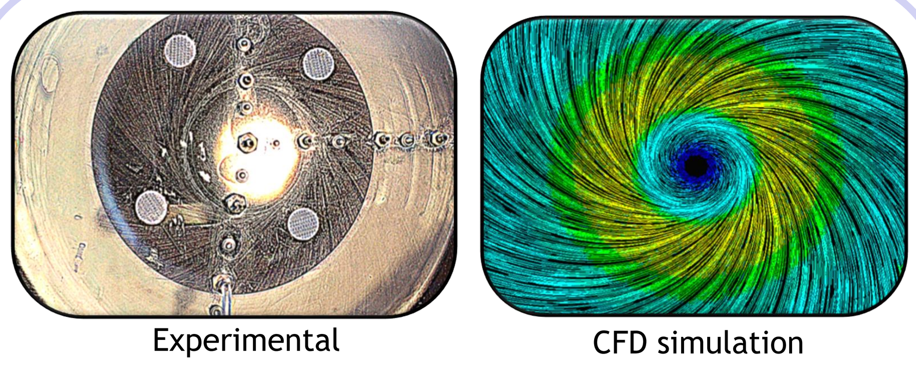
No-slip condition breaks cyclostrophic balance

→ Local radial velocity peak balances pressure gradient

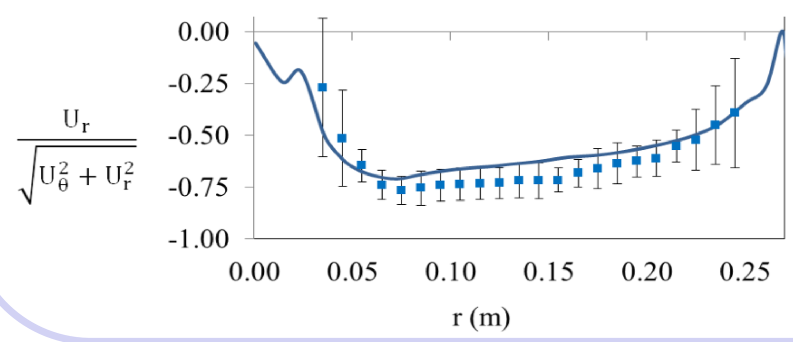
Higher U_r due to jets



Surface streamline angles



Experimental CFD simulation

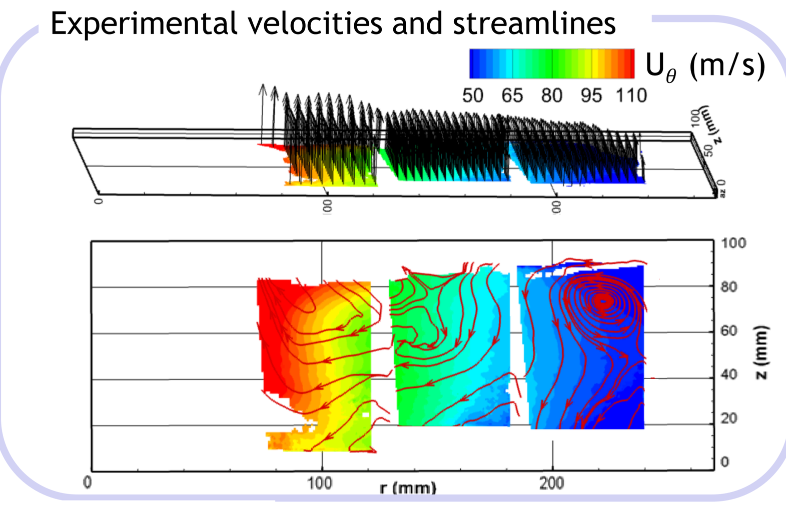


Secondary Flow Features: Counterflow

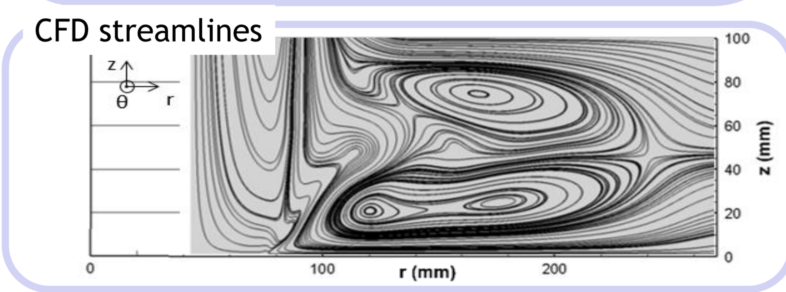
- Jet entrainment induces a flow reversal.
- Experimental detection of vortex core and stagnation points.
- Tracers needed for PIV are affected by strong centrifugal forces justifying measurement of counterflow:
  - further pushed towards circumferential wall,
  - more compact,

  than in the CFD simulations.

Experimental velocities and streamlines



CFD streamlines



Conclusions

- The bulk flow through the GVU is dominated by the azimuthal velocity exhibiting free-swirl flow in the disc part and solid body-like rotation near the central exhaust.
- Radial jets appear near the two end-walls of the unit due to the imbalance between the centrifugal force and radial pressure gradient.
- Swirl decay due to exhaust wall friction generates an adverse pressure gradient along the exhaust line resulting in an extended backflow.
- Jet entrainment of the bulk gas in the disc part of the unit causes a second flow reversal resulting in the counterflow.

Future Work

- Combination of kinetic models with CFD code to study the effect of the secondary flows in processes such as combustion.
- Particulate flow CFD simulations to study the effect of bed formation on secondary flow features.

Acknowledgements

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